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THE EFFECT OF SPACING ON THE YIELD-PROTEIN RELATIONSHIP OF WHEAT AND BARLEY

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The undersigned hereby certify that they have read and recommend to the Committee on Graduate Studies for acceptance a thesis on "The effect of spacing on the yield-protein relationship of wheat and barley", submitted by A. A. Guitard, B.Sc., in partial fulfilment of the requirements for the degree of Master of Science.

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THE EFFECT OF SPACING ON THE YIELD-PROTEIN RELATIONSHIP OF WHEAT AND BARLEY

A. A. Guitard
Department of Plant Science

A THESIS
submitted to the University of Alberta
in partial fulfilment of the
requirements for the degree of
MASTER OF SCIENCE

Edmonton, Alberta
April, 1947

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THE EFFECT OF SPACING ON THE YIELD-PROTEIN RELATIONSHIP OF WHEAT AND BARLEY

A. A. Guitard

INTRODUCTION

Generally speaking, the most important agronomic characteristic of cereals is yield. At present it is necessary to use much land and labor over a period of six to seven years from the initial head selection to the reliable determination of yielding ability. If it were possible to devise a method of eliminating the low-yielding selections, or at least a large percentage of them, prior to the yield trial stage, the work of the plant breeder would be greatly facilitated.

Grant (6) found that a strong negative relationship exists between yielding ability and protein content for both wheat and barley. From this he concluded that protein content can serve as a valuable criterion in the selecting or discarding of certain strains from early-generation hybrids of wheat and barley. It was his opinion that protein determinations could be made on head-row material of all strains which had been selected on the basis of a few agronomic and morphological characteristics. Then, in the case of hard red

spring wheat, keeping the negative yield-protein relationship in mind, approximately 15 per cent of the selections showing the highest protein content could be discarded since their yielding ability would in all probability be low. Approximately 15 per cent of the selections having the lowest protein content could be discarded for this characteristic alone. With slight variations, depending on whether high-yielding-low-protein or high-yielding-high-protein varieties were desired, this method of elimination could be used equally well on other cereal crops.

If this method of elimination is possible a considerable saving in land, labor, and time could be effected. This would be accomplished by reducing by 30 to 40 per cent the present number of selections carried up to and through the yield trials.

The desire for a critical examination of some of the factors that would enter into the use of protein content as an indication of yielding ability in early-generation hybrids led to the instigation of this study. The main object is to examine, at least in part, the feasibility of using protein content of head-rows or even individual plants as an indication of the yielding ability of selections. Of a secondary nature is the substantiation of the correlation and regression values obtained by Grant (6) for wheat and barley.

LITERATURE REVIEW

Yield has been considered a major agronomic characteristic of cereals since the time man took his first faltering steps toward crop improvement. Protein content, as a measure of cereal quality, is of a far more recent origin and it is only within the last 45 years that the relationship between yield and protein content has become known. For the greater part of this period it has been considered an interesting but hardly important association. However, since 1930, the importance of this relationship has been more widely recognized.

Earlier workers emphasized the effect of environment, soil heterogeneity, and climatic conditions, upon the association of yield and protein content. Not until very recently have studies been made of the yield-protein relationship of numerous segregates from a single cross. Periodically studies of the effect of cultural treatments on yield and protein content have been conducted. There have also been a limited number of studies carried out on the yield-protein relationship of single plants of a variety.

As studies of the relationship between yield and protein content have been reviewed in full by both Berg (2) and Grant (6) it seems hardly necessary to give the details here. In general, the conclusions were that there is a highly significant negative correlation and regression between

yield and protein content for both wheat and barley. In most studies the correlation between yield and protein content became stronger as moisture decreased. However, because of its significance to this study, some mention of the work of Malloch and Newton (8) will be made here.

Malloch and Newton (8) tested the relationship between yield and protein content of a single variety as affected by soil variation. During two consecutive years a field that was level and showed no visible soil variation was sown with Red Bobs wheat. Prior to harvest 50 eighteen-foot rows were cut at random from the field. Yield was found to be more variable than protein content. The protein content varied more in 1930 than it did in 1931 and the yield, on the other hand, showed more variation in 1931 than it did in 1930. The authors concluded that single plots are unreliable for making varietal comparisons of yield and protein content.

The yield-protein relationship of selections from the same cross has been studied by both Berg (2) and Grant (6). Grant, working with 100 random selections of a Bunyip x Dicklow cross sown at two stations during two consecutive years, obtained the following yield-protein correlation coefficients: on gray soil, -0.666 and -0.641; on black soil, -0.806 and -0.527. The corresponding regression coefficients of protein on yield were -0.091, -0.079, -0.053, and -0.048. For similar experiments with 100 selections of a barley

cross, Trebi x Peatland, on black soil during two years he obtained correlation coefficients of -0.533 and -0.761 with respective regression coefficients of -0.044 and -0.066. Berg, working with 48 winter wheat selections from the cross (Bankuter 178 x 3922)x Aring obtained a correlation coefficient of -0.474 ± 0.113 for yield and protein, with a regression coefficient of 0.00088 (approximately -0.060 when based on yield in bushels per acre). The correlation coefficient obtained by Berg is slightly lower than those obtained by Grant (6) for both wheat and barley. However, all correlation coefficients are comparable in that they are negative and highly significant. Both Grant and Berg obtained highly significant negative yield-protein regression coefficients for their tests. The coefficients agree very closely as to magnitude despite the fact that Grant used random selections from a cross while the strains used by Berg were the product of rigorous selection for high protein content.

The association of yield and protein content as affected by variations in cultural conditions has received very little attention. However, an extensive study of the effect of plant spacing upon yield was carried on by Engledow and Ramiah (5). The authors worked with three varieties of wheat at spacings of 6" x 1" and 6" x 2". They observed that when the test was sown early there was only a suggestion of a greater yield per unit area for the close spacing. When late sowing was practised, the wider spacing gave an

increase in yield per unit area of 18 per cent over that of the close spacing. For early seeding the average yield per plant for the three varieties showed an 84 per cent increase of the wider spacing over the narrow spacing. For the narrow spacings the late seeding gave a 25 per cent greater average yield per plant than did the early seeding. The late seeding at the wider spacing gave a 171 per cent increase in average yield per plant over the early seeding at the narrow spacing. The increased spacing also produced a significant increase in the average number and size of heads per plant. A very interesting point in this study is that for each of the three varieties all increases due to increased spacing were of approximately the same order.

Anderson _et al_ (1) observed that the seed and forage yields of brome grass increased with the application of nitrogen up to approximately 100 pounds of the element per acre. Protein percentages for the fairly mature forage sampled in the study were not increased appreciably by amounts of nitrogen up to 100 pounds per acre. However, rates of 140 and 200 pounds per acre increased protein percentages appreciably without increasing yield beyond the level attained when 100 pounds of nitrogen per acre was applied.

The variation in protein content and yield and the association of these characters for individual plants of a variety have also received a rather limited amount of attention.

In experiments to determine the plant variability of early-generation hybrids Clark and Quisenberry (4) used as check varieties Kota and Marquis wheats. In 1926 the yields of individual plants of Marquis were found to vary from 1 to 13 grams, and protein content from 12.5 to 16.5 per cent. In 1927, yield varied from 5 to 8 grams and protein content from 14.8 to 16.3 per cent. In 1926, the yields of individual plants of Kota varied from 1 to 15 grams, and protein content from 11.5 to 19.5 per cent. In 1927, yield varied from 7 to 13 grams per plant and protein from 15.3 to 16.8 per cent. The variations of the hybrids were greater in all cases. These results indicate that variation in yield of individual plants of a variety is greater than variation in protein content. The results also indicate that the range of variations for both yield and protein differ from year to year and between varieties.

Clark (3), in testing F_2 plants of Marquis-Hard Federation crosses, obtained a yield-protein correlation of -0.231 ± 0.027. Although the correlation value is not high it is significant. For the F_3 plants of the same cross tested at two different locations, he obtained yield-protein correlation coefficients of +0.256 ± 0.042 and -0.732 ± 0.018. The author accredits the variation between the first two and the third correlation coefficient to the fact that the first two tests were carried out under conditions of excessive moisture, while the third test experienced a severe drought throughout

the major portion of the growing period. The positive correlation obtained between yield and protein content for the second test is believed to be due to the great amount of soil heterogeneity present in the test.

SECTION A

THE YIELD-PROTEIN RELATIONSHIP OF HYBRIDS IN YIELD TESTS

Introduction

The purpose of this portion of the study is to substantiate the work done by Grant (6) and to give continuity between his work and that to be presented in Section B. As this portion is subordinate to the main problem being studied, the tests contain only 50 of the original 100 selections used by Grant (6).

Materials and Methods

Wheat

The cross used for study of the yield-protein relationship was Bunyip x Dicklow, used by Grant (6). Both parents are soft white wheats. Bunyip is characterized by high protein and low yield, while Dicklow is noted for low protein and high yield. The hybrid seed was grown in bulk plots until the F_4 generation in 1940, when a random selection

of 100 plants was made. These selections were increased during 1941 and grown in yield tests in 1944 and 1945 by Grant (6).

The population was reduced to 50 selections. In order to obtain a representative sample of the original 100 selections, the yields for 1944 and 1945 at the two stations, Edmonton and Fallis, were averaged, placed in descending order of yield, and every second selection chosen. Yield trials were carried out in 1946 at both Edmonton (black soil) and Fallis (gray soil).

The field plot design was a simple randomized block with four replicates. Each plot consisted of three rows, 18.5 feet long and 9 inches apart. The plots were sown at the rate of 1.25 bushels per acre using seed of the 50 selections from the yield test at Edmonton carried out in 1944. No fertilizer was added at either station.

The centre row of each plot was trimmed to 16.5 feet at maturity, harvested by hand, wrapped, and threshed separately, in a rod-row thresher. The yield was recorded.

Protein content was determined on composite samples of seed from the four replicates. No analysis of variance could therefore be applied. Analysis of variance was applied to the yield data in the manner outlined by Hayes and Immer (7). Yield-protein correlation and regression coefficients were calculated.

Barley

The cross used in this study was Trebi x Peatland. Peatland is characterized by high protein content and low yield, while Trebi is consistently a high-yielding, low-protein variety. Grant (6) studied the yield-protein relationship of 100 selections from this cross. He described the history of these selections.

As in the case of wheat, the population was reduced to 50 selections. This was done in the same manner as for the wheat selections. Yield trials were carried out in 1946 at both Edmonton (black soil) and Fallis (gray soil) using seed of the 50 selections from the yield test at Edmonton carried out in 1944.

The same field plot design, type of plot, methods of harvesting and analysis were applied to the barley selections as have already been described for wheat. The seeding rate for the barley was 2.00 bushels per acre.

Experimental Results

Wheat

Edmonton (black soil)

Except for an extremely dry period during and for two weeks following seeding, the season was highly

satisfactory. Germination was even and sufficient rainfall produced an excellent growth. The majority of the plots exhibited a tendency to lodge, but for no selection was lodging of such a degree as to produce an appreciable loss during harvesting.

The results of the analysis of variance for yield are given in Table I. A highly significant difference in yield was indicated for selections, while there was no apparent significant difference in yield between replicates.

TABLE I

Results of the analysis of variance for yield of wheat selections, Edmonton, 1946

Variance due to	D.F.	Mean square	F
Selection	49	517.16	5.13**
Replicate	3	268.19	2.66
Error	147	100.76	
Total	199		

** Exceeds the 1% point.

As has already been mentioned, the protein determinations were made on composite samples from the four replicates, and no analysis of variance was possible.

The relationship between yield in bushels per acre and protein content in per cent was found to be negative and highly significant, having a regression value of $b_{py} = -0.058$. The regression equation for protein content (p) in terms of yield (y) is $p = 14.39 - 0.058\ y$. The degree of association between yield in bushels per acre and protein content in per cent is expressed by the correlation coefficient r_{py}, which for this experiment has the highly significant value of -0.683.

Fallis (gray soil)

Growing conditions were excellent throughout the entire season. No lodging occurred in the test.

The results of the analysis of variance for yield are given in Table II. A highly significant difference in yield was obtained for selections. The difference in yield between replicates was just significant.

TABLE II

Results of the analysis of variance for yield of wheat selections, Fallis, 1946

Variance due to	D.F.	Mean square	F
Selections	49	302.48	4.10**
Replicates	3	205.40	2.78*
Error	147	73.83	
Total	199		

** Exceeds the 1% point * Exceeds the 5% point

As at Edmonton a highly significant negative relationship was obtained for yield (y) and protein content (p) (b_{py} = -0.063). The regression equation for protein in terms of yield is $p = 10.00 - 0.063\ y$. The correlation coefficient (r_{py} = -0.762) was highly significant.

Barley

Edmonton (black soil)

Good growing conditions prevailed throughout the season, resulting in heavy growth. Serious lodging was encountered in many cases, but owing to careful harvesting, the mechanical error was held to a minimum.

The results of the analysis of variance for yield are presented in Table III. A highly significant difference in yield was found between selections, while there was no significant difference between replicates.

A highly significant negative yield-protein regression coefficient of -0.050 was obtained. The regression equation for protein (p) in terms of yield (y) is $p = 15.86 - 0.050\ y$. A highly significant negative correlation coefficient of -0.483 was also obtained.

TABLE III

Results of the analysis of variance for yield
of barley selections, Edmonton, 1946

Variance due to	D.F.	Mean square	F
Selections	49	274.41	2.03**
Replicates	3	243.07	1.80
Error	147	135.00	
Total	199		

** Exceeds the 1% point.

Fallis (gray soil)

Excellent growing conditions throughout the season resulted in abundant and uniform plant growth. No lodging occurred throughout the season.

The results of the analysis of variance for yield are given in Table IV. A highly significant difference in yield was obtained for selections, but the difference for replicates was not significant.

As at Edmonton a highly significant negative regression of -0.091 was obtained for yield and protein content. The regression equation for protein (p) in terms of yield (y) is $p = 14.17 - 0.091\,y$. A highly significant negative correlation coefficient of -0.762 was also obtained.

TABLE IV

Results of the analysis of variance for yield of barley selections, Fallis, 1946

Variance due to	D.F.	Mean square	F
Selections	49	336.83	4.11**
Replicates	3	4.62	0.06
Error	147	82.02	
Total	199		

** Exceeds the 1% point.

Discussion

The results obtained by Grant (6) in studies of the yield-protein relationships of wheat and barley have been substantiated by the present study. This was to be expected as the same material was used in both investigations. However, only 50 selections of each crop were used in the present study instead of the original 100 selections used by Grant. It is realized that, for most accurate comparison of the present study with that carried out by Grant, it would have been advisable to consider only those selections in Grant's study which were used here. However, such a comparison was not made, partly because results of the present study were in good agreement with those of Grant, and partly because this phase of the present study was included

principally to connect Grant's work with current work on the effect of cultural treatments on the yield and protein content of wheat and barley.

To facilitate comparison of Grant's results (6) with those of the present study, correlation and regression coefficients are presented in tabular form below:

	r_{py}	b_{py}
Wheat		
Edmonton 1944 (Grant)	-0.806	-0.053
Edmonton 1945 (Grant)	-0.527	-0.048
Edmonton 1946	-0.683	-0.058
Fallis 1944 (Grant)	-0.666	-0.091
Fallis 1945 (Grant)	-0.641	-0.079
Fallis 1946	-0.762	-0.063
Barley		
Edmonton 1944 (Grant)	-0.533	-0.044
Edmonton 1945 (Grant)	-0.761	-0.066
Edmonton 1946	-0.483	-0.050
Fallis 1946	-0.762	-0.091

It can readily be seen that there is good agreement between the studies during the different years at both Edmonton and Fallis.

It was also noted that the errors due to soil variability within the tests carried out in 1946 were very small. For barley, at both Edmonton and Fallis, the differences in yield between replicates were not significant, while for the wheat the difference was not significant at Edmonton and just significant at Fallis.

SECTION B

THE YIELD-PROTEIN RELATIONSHIPS OF HYBRIDS SOWN AT DIFFERENT SPACINGS

Introduction

When sowing head-rows the intra-row spacing usually depends upon the amount of seed available. Thus rows are obtained in which the plants are very close together, and others in which the plants are widely spaced. The purpose of this section of the study is to determine the effect of plant spacing within the row upon protein content, yield, and the relationship between the two. As it would be a prodigious task to attempt to duplicate all spacings that might occur in head-rows the one- and twelve-inch spacings were selected so as to include the extreme range of spacings that might be encountered, and then an intermediate six-inch spacing was included.

Materials and Methods

Wheat

The 50 Bunyip x Dicklow random selections used in

Section A, plus three check varieties, Bunyip, Dicklow, and Bunyip x Dicklow H-43-8, were used. To obtain results approximating those obtained when working with head-rows, the selections were grown in non-replicated, single, five-foot-row plots, spaced one foot apart.

The experiment was set up in three banks. The first bank contained the selections sown at one-inch spacings within the rows, the second bank at six-inch, and the third at twelve-inch spacings. Each check variety appeared twice in a bank, two rows being sown at the beginning of the bank, two in the centre, and two at the end. The checks were randomized so that in no case did the two rows of a check variety appear together in the bank. For each spacing the selections were sown in the same order within the bank and the banks for the one-, six-, and twelve-inch spacings sown side by side in the field. There was a 3½-foot roadway left between banks. By the use of this arrangement the one-, six-, and twelve-inch spacings of each selection were directly opposite each other in each bank, thus reducing to some extent the error due to land heterogeneity.

In the case of the one-inch spacing 61 seeds were counted out and sown with a Kemp V-belt seeder. For the six- and twelve-inch spacings the seeding was done by hand. At each interval two holes approximately one inch apart were made, a seed dropped in each hole, and covered. An effort was made to place the seeds at equal depths approximating as

closely as possible the depth of seeding of the one-inch spacings. When filling the holes an attempt was made to pack the soil to the same degree as accomplished by the Kemp V-belt seeder for the one-inch spacings.

When the seedlings had reached a height of one to two inches the rows of the six- and twelve-inch spacings were checked. Where both seeds had germinated one of the seedlings was carefully removed so as not to injure the one remaining. In a few of the cases neither of the seeds germinated. To eliminate the effect that would be caused by gaps, plants of the same selection were transplanted into these positions. The positions of these plants were noted on the field plan and they were removed just prior to harvesting.

Similar tests were conducted at both Edmonton (black soil) and Fallis (gray soil). Field notes were taken throughout the growing season. At both stations the plots were kept completely free from weeds.

To eliminate border effect, six inches was removed from each end of the one-inch-spaced rows just previous to harvesting. For the six- and twelve-inch spacings the plants at each end of the row were removed. The transplants and the plants on either side of any appreciable gap were also removed. The plants were then pulled, and counted, and each plot wrapped individually to prevent mixing and the loss of seed.

The plots were threshed by a head-row thresher, the seed cleaned, weighed, and yield recorded. The total yield was divided by the number of plants harvested to obtain the average yield per plant for each selection at each spacing. Protein determinations were run on each sample.

Correlation coefficients were determined for yields and protein contents at each spacing, for the yields obtained in the yield tests in Section A and the yields at the different spacings, and for the protein contents obtained in Section A and the protein contents at the different spacings. The significance of the differences between the mean yields, and between the mean protein contents at the different spacings were also calculated.

Barley

The 50 Trebi x Peatland random selections used in Section A, plus two check varieties, were used. In these tests only the two parental varieties, Trebi and Peatland, were used as checks. The plot arrangement and method of seeding were identical with those for wheat, the only exception being that the two check varieties of barley appeared three times in each bank. Similar tests were carried out at Edmonton (black soil) and Fallis (gray soil). The barley received the same treatment as the wheat during the growing season and harvest operations. For each selection yield on a single-

plant basis and protein content were determined. As for the wheat, correlation coefficients and means were calculated.

Throughout this section of the study the symbols used in the presentation of the data are as follows:

y = yield for yield tests (Section A)
y_1 = yield for 1-inch spacings
y_2 = yield for 6-inch spacings
y_3 = yield for 12-inch spacings
p = protein content for yield tests (Section A)
p_1 = protein content for 1-inch spacings
p_2 = protein content for 6-inch spacings
p_3 = protein content for 12-inch spacings.

Experimental Results

The tests to be discussed were carried out with wheat and barley at Edmonton and Fallis. At both locations climatic conditions were satisfactory throughout the growing season. At Edmonton an obvious source of error, owing to the lateness of maturity of a number of the selections at the 12-inch spacings, entered into the wheat test. The wheat test at Fallis suffered from severe attacks of both leaf and stem rust just after the plants headed. As there appeared to be very little variation in the degree of infestation, no

record was made of the percentage infestation of the different selections. Since barley has a shorter growth period than wheat, delayed maturity at the wider spacings was not an important problem at Edmonton. Figures 1 and 2 illustrate the variations in time of maturity between selections and spacings. As previously mentioned, the situation for wheat was similar but more extreme.

In Table V the mean yields and mean protein contents and the yield and protein content ranges are tabulated. The means for each spacing are based on 56 values. The ranges were arrived at by taking the difference between the highest and lowest values obtained.

In Table VI the mean differences between spacings, and the significance of the differences, are given for both yields and protein contents. Also tabulated are the ranges of differences, calculated by taking the difference between the highest and lowest values for each spacing comparison. The standard errors of the difference were calculated according to the method used by Hayes and Immer (7) in the testing of the significant difference of means of paired values.

For all tests increased spacings were accompanied by highly significant increases in mean yields per plant, and by increased ranges of yields. As would be expected the greatest increases in mean yields were between the one- and twelve-inch spacings. For the wheat at Edmonton the increase between the one- and six-inch spacings was approximately

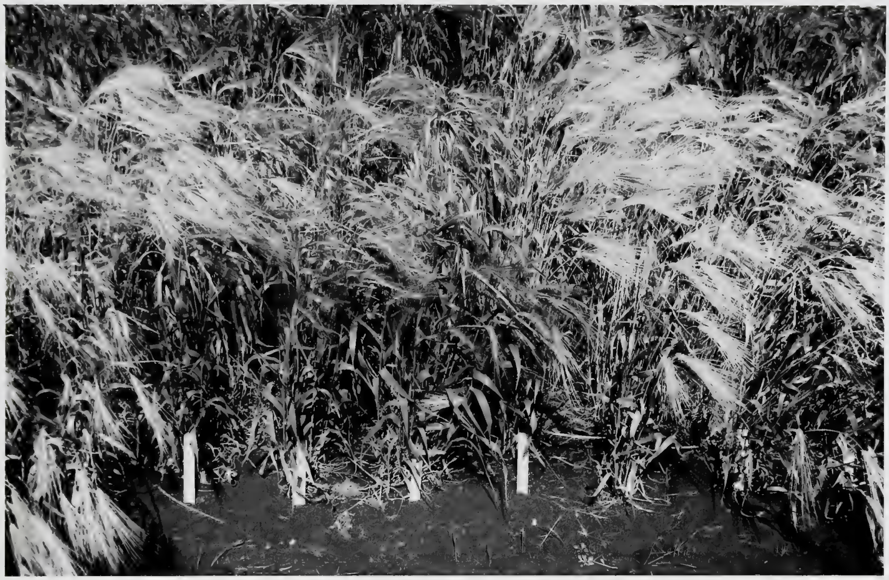

Figure 1

Variations in maturity and other agronomic characteristics exhibited by the barley selections at the 1-inch spacings, Edmonton

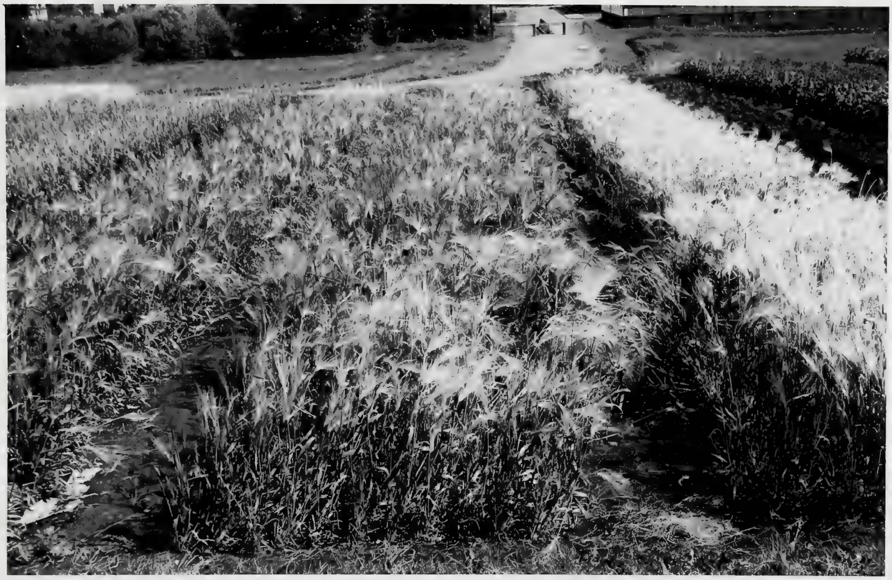

Figure 2

Variations in time of maturity exhibited
by the 1- 6- and 12-inch spacings
of barley, Edmonton

TABLE V

Means and ranges of yields and protein contents of 56 selections - 1946

			Yield (gm./pl.)		Protein (%)	
		Spacing	Mean	Range	Mean	Range
Wheat:	Edmonton	1-inch	3.8	4.2	12.0	4.5
		6-inch	13.3	17.1	11.5	4.1
		12-inch	16.6	27.2	11.4	3.5
	Fallis	1-inch	3.2	3.7	7.0	2.4
		6-inch*	12.2	16.2	7.8	3.2
		12-inch	20.9	24.2	8.6	4.3
Barley:	Edmonton	1-inch	3.6	8.1	13.5	5.4
		6-inch	17.0	23.6	14.4	4.6
		12-inch	29.1	38.2	14.5	5.0
	Fallis	1-inch	3.0	2.5	8.6	3.1
		6-inch	15.1	8.9	9.4	4.2
		12-inch	22.0	24.9	11.2	7.0

* Means of 54 values.

three times as great as that between the six- and twelve-inch spacings. This striking decline in the yield increase as the twelve-inch spacings were approached was, at least in part, due to the immaturity of a number of the selections at the time of harvest. In the case of the wheat at Fallis and the barley at Edmonton the increases between the one- and six-inch spacings and between the six- and twelve-inch spacings were similar. For the barley at Fallis the increase between the one- and six-inch spacings was twice as great as that

TABLE VI

Mean differences between spacings for both yields and protein contents of 56 selections - 1946

	Spacings	Range of differences	S.E. of differences	Mean difference	t-value
Wheat					
Edmonton	y_3-y_1	27.9	0.817	12.8	15.70**
	y_3-y_2	28.3	0.791	3.3	4.21**
	y_2-y_1	15.9	0.442	9.5	21.47**
	p_1-p_3	4.5	0.129	0.6	4.88**
	p_2-p_3	4.5	0.105	0.1	1.24
	p_1-p_2	3.1	0.090	0.5	5.44**
Fallis	y_3-y_1	22.8	0.696	17.7	25.40**
	y_3-y_2	22.1	0.686	8.8	12.86**
	y_2-y_1	13.6	0.392	9.0	22.86**
	p_3-p_1	4.2	0.126	1.6	12.62**
	p_3-p_2	4.8	0.107	0.8	7.66**
	p_2-p_1	4.4	0.125	0.8	6.24**
Barley					
Edmonton	y_3-y_1	40.5	1.357	25.4	18.75**
	y_3-y_2	39.3	1.223	12.1	9.90**
	y_2-y_1	22.2	0.635	13.3	20.94**
	p_3-p_1	5.9	0.167	1.0	6.23**
	p_3-p_2	3.1	0.094	0.1	1.28
	p_2-p_1	4.9	0.138	0.9	6.67**
Fallis	y_3-y_1	23.3	0.687	19.0	27.66**
	y_3-y_2	21.1	0.465	6.8	14.62**
	y_2-y_1	15.0	0.329	12.1	36.78**
	p_3-p_1	5.2	0.182	2.7	14.84**
	p_3-p_2	3.7	0.122	1.8	14.75**
	p_2-p_1	3.4	0.105	0.8	7.62**

** Significant to the 1% point (2.67).

between the six- and twelve-inch spacings. Except for the twelve-inch-spaced wheat at Edmonton, all spacings at Edmonton gave higher mean yields per plant than did the corresponding

spacings at Fallis.

The ranges of yields within the spacings for all tests increased consistently as spacings were increased. For both wheat and barley the ranges for the spacings at Edmonton were higher than those for the corresponding spacings at Fallis. Except in the case of the barley at Fallis the range increases were greater between the one- and six-inch spacings than between the six- and twelve-inch spacings. For the barley spacings at Fallis the opposite relationship appeared.

The ranges of the differences in yields were larger for the comparisons at Edmonton than for the parallel comparisons at Fallis. For all tests the ranges of the differences in yield were also smallest for the comparisons between the one- and six-inch spacings, and approximately equal in magnitude for the comparisons between the six- and twelve-inch spacings and the one- and twelve-inch. The standard errors of the differences were likewise larger at Edmonton than at Fallis, and increased from the comparisons between the one- and six-inch spacings to those between the six- and twelve-inch spacings, to those between the one- and twelve-inch spacings.

As would be expected, considering the difference in soil types at the two stations, the mean protein contents for all spacings at Edmonton were higher than those for the comparable spacings at Fallis. Except in the case of the wheat test at Edmonton increased spacings produced increases

in mean protein contents. At Edmonton increased spacings were associated with decreasing mean protein contents for wheat. There were highly significant decreases between the one- and six-inch and one- and twelve-inch spacings and a non-significant decrease between the six- and twelve-inch spacings. At Fallis there were constant increases in the mean protein contents of the wheat selections, up to the twelve-inch spacings. In the barley test at Edmonton increased spacing caused highly significant increases in mean protein contents between the one- and twelve-inch and the one- and six-inch spacings and a non-significant increase between the six- and twelve-inch spacings. At Fallis there were highly significant increases between all spacings, with a greater increase between the six- and twelve-inch than between the one- and six-inch spacings. In the case of both barley and wheat, at Edmonton increased spacings were accompanied by decreased protein ranges, and at Fallis by increased protein ranges.

As can be seen in Table VI the ranges of the differences and the standard errors of the difference for the different spacings indicate no general trend.

The relationships between the yields and protein contents at the different spacings, the yields at the different spacings, and the corresponding yields in the yield trials, and the protein contents at the different spacings and those of the yield trials, were determined. The co-

efficients for yields and protein contents within the spacings are based on the 50 selections plus 6 check varieties. Where the relationships of the yields and protein contents to their respective values in the yield trials were calculated the coefficients are based on the results of the 50 selections. The correlation coefficients are tabulated in Table VII.

TABLE VII

Correlation coefficients for the wheat and barley spacing tests - Edmonton and Fallis, 1946

Correlation coefficient	Wheat		Barley	
	Edmonton	Fallis	Edmonton	Fallis
$r_{p_1 y_1}$	-0.356**	0.185	-0.603**	0.450**
$r_{p_2 y_2}$	0.001	-0.377**	-0.540**	-0.133
$r_{p_3 y_3}$	-0.194	-0.211	-0.594**	-0.422**
$r_{y_1 y}$	0.704**	0.244	0.403**	0.423**
$r_{y_2 y}$	0.519**	0.261	0.122	0.374**
$r_{y_3 y}$	0.513**	0.255	0.013	0.508**
$r_{p_1 p}$	0.715**	0.586**	0.351*	0.742**
$r_{p_2 p}$	0.276*	0.168	0.383**	0.663**
$r_{p_3 p}$	0.183	0.227	0.376**	0.587**

* Exceeds the 5% point.
** Exceeds the 1% point.

The relationships between yields and protein contents within the spacings were inconsistent. At spacings of one inch the relationships were negative and highly significant for both wheat and barley at Edmonton, while at Fallis it was positive but not significant for wheat and positive and highly significant for barley. For the six-inch spacings the relationships were negative and highly significant for wheat at Fallis and barley at Edmonton, but not significant for the other two tests. The twelve-inch spacings gave negative relationships for all tests, but only those for barley at Edmonton and Fallis were highly significant.

The yields at the different spacings, when correlated with the yields of the yield trials, outlined in Section A of this study, gave variable results. Wheat at Edmonton gave highly significant positive correlations for all spacings, whereas at Fallis the coefficients were all positive but non-significant. For the barley at Edmonton the relationships were all positive but only that for the one-inch spacings highly significant, while at Fallis all relationships were highly significant. Although for the wheat at Fallis none of the yields at the different spacings showed significant relationships to the yields of the yield trials, the correlation coefficients were all positive and of equal value. The relationships between the yields of the one-inch spacings and those of the six-inch spacings, and the

yields of the one-inch spacings and those of the twelve-inch spacings were highly significant ($r_{y_1y_2}$ = 0.434 and $r_{y_1y_3}$ = 0.398). From the consistency of the low correlation coefficients, and the highly significant relationships between the yields of the different spacings, it appears that the error between spacings was less extreme than it would normally have been had the large error between selection yields been caused entirely by soil variability. The correlation coefficients also indicated that the yields of the adjacent barley tests were also more accurate than were those of the wheat. On the basis of the foregoing it seems reasonable to assume that a large portion of the error between selection yields was due to the varying effects of the rust epidemic upon the selections, rather than to soil variations.

When the protein contents for the one-inch spacings were correlated with the protein contents of their respective yield trials all correlation coefficients were positive and highly significant, except in the case of the barley at Edmonton, which was only significant. The correlation coefficients for the six- and twelve-inch spacings of barley at Edmonton were highly significant, but not significantly higher than the coefficient for the one-inch spacings. The protein contents for the barley at Fallis, when correlated with the protein contents of the yield trial, gave highly significant relationships for all spacings.

It can be readily noticed from the correlation coefficients in Table VII that both the mean yields and mean protein contents of the plants at the one-inch spacings are in better accord with the yields and protein contents of the yield trials than are those of the wider spacings. This may be due to the greater influence of soil heterogeneity with increased spacings, or to the fact that the means, in the case of yields, and the composite samples analysed, in the case of protein contents, were composed of a greater number of individual plants at the one-inch spacings than at the wider spacings. It can also be noticed, when the over-all picture is considered, that the protein contents of the one-inch spacings, when correlated with their related values in the yield trials, do not give significantly better correlation coefficients than do the yields when correlated with their related values in the yield trials. Thus it appears that soil heterogeneity produces similar relative variations in both yields and protein contents.

Discussion

All increased spacings were accompanied by corresponding increases in mean yields per plant, with a gradual reduction in the unit increase as spacings were increased. The results indicate that, under similar conditions, the

maximum plant yields would have been reached at spacings somewhat wider than 12 inches. With increased spacings there were also increases in yield ranges within the spacings and increases in the ranges of the differences for the comparisons. This indicates that the inherently high-yielding selections have a greater ability to make use of the increased nutrient supply and improved growth conditions than have their inherently lower-yielding relatives, thus giving greater yield increases.

As the protein contents are recorded as percentages of the total kernel material, their increase or decrease with increased spacings depends on the rate of increase in nitrogen assimilation in relation to the rate of increase in the production of the other components of plant yield. As has already been stated, in all cases mean yields increased with increased spacing. This was also the case for the protein contents, except for the wheat test at Edmonton where a decrease was obtained.

With increased spacing the wheat at Fallis showed a constant increase in protein contents, with no indication of falling off up to the twelve-inch spacings, whereas that of the barley increased at a greater rate as spacings were increased. Considering the nitrogen-poor condition of the soil at Fallis this is to be expected, as the increased spacings cause a greater relative increase in the availa-

bility of nitrogen than in the availability of the other plant nutrients. Thus, despite the negative relationship existing between the two there was an increase in both yields and protein contents at Fallis. Although barley showed the greater yield increases, it also gave the greater increases in protein content with increased spacings, indicating that its ability to make use of the increased nitrogen supply is superior to that of wheat. The wheat at Edmonton showed a decrease in mean protein contents as spacings were increased, and the barley an increase. Both the increase for barley and the decrease for wheat tended to fall off as the twelve-inch spacings were approached, indicating that either no change in protein contents or a reversal of the trend would be associated with still greater increase in spacings. At Edmonton, as at Fallis, the barley showed the greater ability to utilize the increased supply of soil nitrogen.

At Edmonton increased spacings caused a small decrease in the ranges of protein contents and at Fallis a noticeable increase. The ranges of differences between the comparisons formed no comprehensive trends.

The correlation coefficients varied extremely throughout the four tests. This inconsistency, the greater part of which was due to soil variations within the tests, is to be expected when dealing with data from non-replicated field experiments. Similar variations were observed by

Malloch and Newton (8) who, over a period of two years, took random samples of Red Bobs wheat from an apparently uniform field. The authors noticed greater variations in yield than in protein content. In the present tests it was also obvious from the correlation coefficients that there was less error in the yields and protein contents of the selections sown at the one-inch spacings than at the wider spacings.

The efficiency of yields and protein contents of the one-inch-spaced 5-foot rows, as criteria for the elimination of low-yielding and high-yielding, thus low-protein-content selections from a population, was examined using the test showing the least apparent soil variations. As both the relationship between the yields of the one-inch spacings and the yields of the yield trial, and the protein of the one-inch spacings and the proteins of the yield trial, were high for the wheat tests at Edmonton ($r_{y_1y} = 0.704$ and $r_{p_1p} = 0.715$) these tests were used.

In Table VIII the selections tested in yield trials during 1944, 1945, and 1946, are presented in descending order of yield. Also given are the same selections from the wheat one-inch spacings at Edmonton, placed in descending order of yield, and the protein contents from this test in ascending order. Assuming a forty percent elimination on the basis of the data of the one-inch spacings, the single asterisks on the left-hand side of the columns indicate the selections eliminated because of high yield, and the double asterisks

TABLE VIII

Distribution of eliminated selections on the yield trials - Edmonton, 1944, 1945, and 1946

Yields (1-inch)	Yields (1944)	Yields (1945)	Yields (1946)	Protein (1-inch)
*21	20*	15	04**	47*
*47	41*	**30*	*12	49*
*26	04**	**11**	*39*	39*
*08	*47*	**37	27	20*
*39	*26	16	07	30*
*34	27	**31*	*34	41*
*49	29	**24	*23	46*
*40	25	*34	*47*	50*
*23	17	**19	28	31*
*12	46*	38	*40	48*
07	*21	06	32	12
27	33	46*	16	26
25	05**	07	41*	29
41	*23	*12	*21	17
38	**30*	22	*26	24
32	07	45	35	32
22	*39*	*39*	25	34
16	*49*	**36**	20*	09
15	28	05**	29	25
28	22	04**	15	27
04	44	50*	02**	28
29	02**	*40	09	33
09	35	09	*49*	35
48	03**	25	46*	44
44	*40	29	18	21
20	*12	44	17	38
10	50*	18	50*	40
06	*08	*21	05**	18
46	06	17	10	08
45	16	*49*	*08	19
35	32	*23	03**	07
18	*34	*26	**24	16
50	10	10	**30*	23
33	38	*47*	44	37
05	**24	33	**19	10
03	**37	41*	06	45
02	15	43	48*	06
01	09	01**	38	15
17	**31*	28	33	43
43	18	27	43	22
**42	48*	20*	**37	14**
**30	**42**	**42**	45	04**
**24	01**	35	**31*	11**
**19	**14**	**13**	22	05**
**13	**36**	*08	**42**	36**
**36	**13**	32	**36**	42**
**31	43	02**	**14**	02**
**14	**11**	03**	**11**	13**
**11	**19	**14**	01**	03**
**37	45	48*	**13**	01**

the selections eliminated because of low yield. Likewise, the single asterisks on the right-hand side of the columns indicate the selections eliminated because of low protein content, and the double asterisks those eliminated because of high protein content. In Table IX the efficiencies of the use of the yields and protein contents of the one-inch spacings in the elimination of the 10 highest yielding and the 10 lowest yielding selections in the yield trials grown during 1944, 1945, and 1946, are given. The index of efficiency of elimination is calculated on a percentage basis, from the number of times top 10 or bottom 10 selections, eliminated on the basis of the results from the one-inch spacings, fall within the corresponding ranges for the yield trials.

TABLE IX

Efficiency of elimination of high and low yielding selections by the yields and protein contents of the 1-inch-spaced wheat - Edmonton

Method	Yield Range	Percentage eliminated			
		1944	1945	1946	Average
Yield	High	20	10	60	30
	Low	60	30	70	53
Protein content	High	40	20	20	27
	Low	60	50	60	57

As is seen in Table VIII, the selections eliminated on the basis of both yield and protein content results from the one-inch spacings, fall in almost random distribution on the yield trials. The distributions are about the same for the years 1944 and 1946. As 1945 was an extremely dry year this seems to have caused a change in the order of yields, thus varying the distribution somewhat. From Table IX it is seen that the efficiency of elimination of the low-yielding selections is almost twice as great as that of the high-yielding selections with a low protein content. This, at best, is only 70 per cent efficient using protein content as the criterion of elimination. Considering the averages there appear to be no appreciable differences in the accuracy of the two methods. Despite the apparent accuracy of yields and protein contents of the selections grown in 5-foot rows in the test used for this illustration (r_{y_1y} = 0.704 and r_{p_1p} = 0.715), the efficiency of elimination obtained was only slightly better than could be expected from the random discarding of selections from a large population. The fact that this accuracy is greater than could normally be expected, especially when using a large number of selections, must also be considered. On the basis of the foregoing results it must be concluded that, without the introduction of replication, neither average plant yields nor protein contents of early generation head-row material are of any value in the elimination of the high-yielding-low-

protein or low-yielding-high-protein selections from a population.

SECTION C

THE YIELD-PROTEIN RELATIONSHIPS OF SINGLE PLANTS OF THE SAME VARIETY

Introduction

The purpose of this section of the study was to examine the possibility of using the protein content or yield of an individual plant as an indication of the yielding ability and protein content of a selection. Individual plants of two varieties of wheat and two varieties of barley were studied. Although the selections previously used are thought to be homozygous, varieties were used to make sure that the variations in yield and protein content would be as small as possible. The individual plant variation in both yield and protein content, the effect of spacings upon these variations and the relationship between the yields and protein contents of the individual plants were determined.

Materials and Methods

Wheat

The two varieties of wheat used were Bunyip and

[illegible]

[illegible] of an individual plant [illegible]
ability, and [illegible]
plants of the variation [illegible]
[illegible]
be so small [illegible]
[illegible]
[illegible] These variations [illegible]

Bunyip x Dicklow H-43-8. Bunyip is the low-yielding-high protein parent of the random selections used in Sections A and B of this study, and H-43-8 a promising high-yielding-low-protein selection from a Bunyip-Dicklow cross made at the University of Alberta.

Each of the two varieties was sown at one-, six- and twelve-inch spacings in 5-foot rows. For the one-inch spacings the plots consisted of three rows; for the six-inch, four rows; and for the twelve-inch, five rows. Each plot was replicated three times in each test. The plots were sown in a split-plot arrangement, the main plot being the variety and the sub-plots within this consisting of the three spacings. The tests were carried out at both Edmonton (black soil) and Fallis (gray soil) during 1946.

Seeding, removal of extra seedlings, and the filling of gaps were carried out in the same manner as described in Section B of this study. Just prior to heading 30 plants from each plot were selected at random and labelled. Care was taken not to label plants that were at the end of a row, adjacent to a gap, or that had been transplanted to fill a gap. Notes were taken on the labelled plants throughout the remainder of the season. At harvest time any of the labelled plants that had obviously suffered mechanical damage or were near a gap were removed. The plots were then pulled and ten labelled plants selected at random from each plot. The heads on each plant were counted, removed, and placed in

an envelope. The samples were threshed and cleaned by hand and the weights recorded. Protein determinations were run on the samples.

Barley

Trebi and Peatland, the two parental varieties of the selections used in Sections A and B of this study, were used in these tests. The plot arrangement, methods of seeding, and the handling of the material throughout the whole of the test period, were the same as those used for the wheat. The tests were carried out at both Edmonton (black soil) and Fallis (gray soil) during 1946.

Experimental Results

The mean yields, mean protein contents, and average yield and protein content ranges are tabulated in Table X. The mean yields and protein contents are based on the analyses of 30 individual plants, 10 from each replicate. The ranges are the differences between the averages of the lowest and the highest values for each replicate. In the graphical presentation of the results, Figures 3 to 6, the average extremes for the ranges are plotted. As in no instance was there a significant relationship between the yields and protein contents of the individual plants, cor-

TABLE X

Mean yields, protein contents, and yield and protein content ranges of individual plants
Edmonton and Fallis - 1946

Variety	Spacing	Yield			Protein content		
		Mean	Range	Stand. dev.	Mean	Range	Stand. dev.
		Wheat					
Edmonton: Bunyip	1-inch	5.5	5.3	1.8	12.9	2.3	1.0
	6-inch	12.3	11.7	4.5	12.2	2.2	0.8
	12-inch	13.4	15.3	5.2	12.0	2.5	0.8
Bunyip x Dicklow H-43-8	1-inch	5.7	5.0	1.6	10.2	1.0	0.6
	6-inch	14.7	11.7	4.2	10.9	2.2	0.6
	12-inch	15.4	14.7	5.0	11.2	3.6	1.2
Fallis: Bunyip	1-inch	4.3	5.7	1.9	8.5	1.9	0.7
	6-inch	11.7	9.7	3.5	8.8	1.9	0.7
	12-inch	17.0	11.3	3.5	9.9	2.4	1.1
Bunyip x Dicklow H-43-8	1-inch	5.1	5.3	1.8	6.8	1.6	0.6
	6-inch	14.7	11.0	3.5	7.7	1.8	0.6
	12-inch	21.8	17.3	5.8	9.6	2.6	1.0
		Barley					
Edmonton: Trebi	1-inch	6.3	4.7	2.0	11.8	2.0	0.7
	6-inch	23.5	18.7	6.0	13.3	2.9	1.0
	12-inch	30.6	25.7	8.4	14.0	3.5	1.4
Peatland	1-inch	4.9	8.0	2.4	13.9	4.0	1.8
	6-inch	16.0	19.7	7.1	16.5	3.6	1.1
	12-inch	19.2	22.4	8.1	16.7	2.7	0.9
Fallis: Trebi	1-inch	4.8	6.7	2.3	7.6	1.8	0.8
	6-inch	18.0	13.4	5.5	8.7	2.1	0.9
	12-inch	23.9	15.7	5.2	9.0	1.7	0.7
Peatland	1-inch	2.9	3.6	1.4	9.9	2.7	0.8
	6-inch	12.7	13.0	4.3	11.7	3.4	1.6
	12-inch	18.2	17.0	5.6	11.6	3.7	1.6

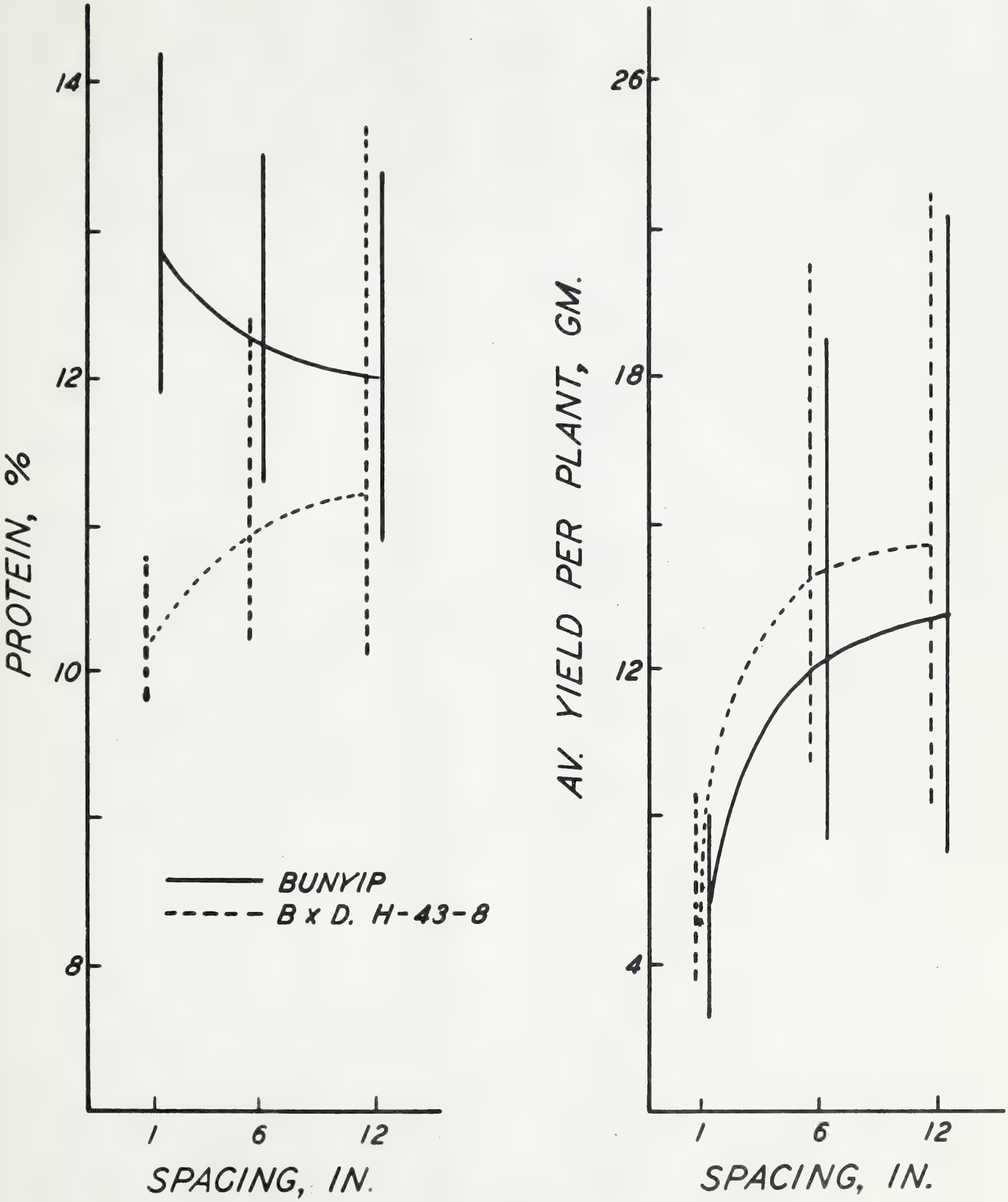

Figure 3

Effect of spacing on mean yields per plant, mean protein contents, and yield and protein content ranges of wheat
Edmonton, 1946

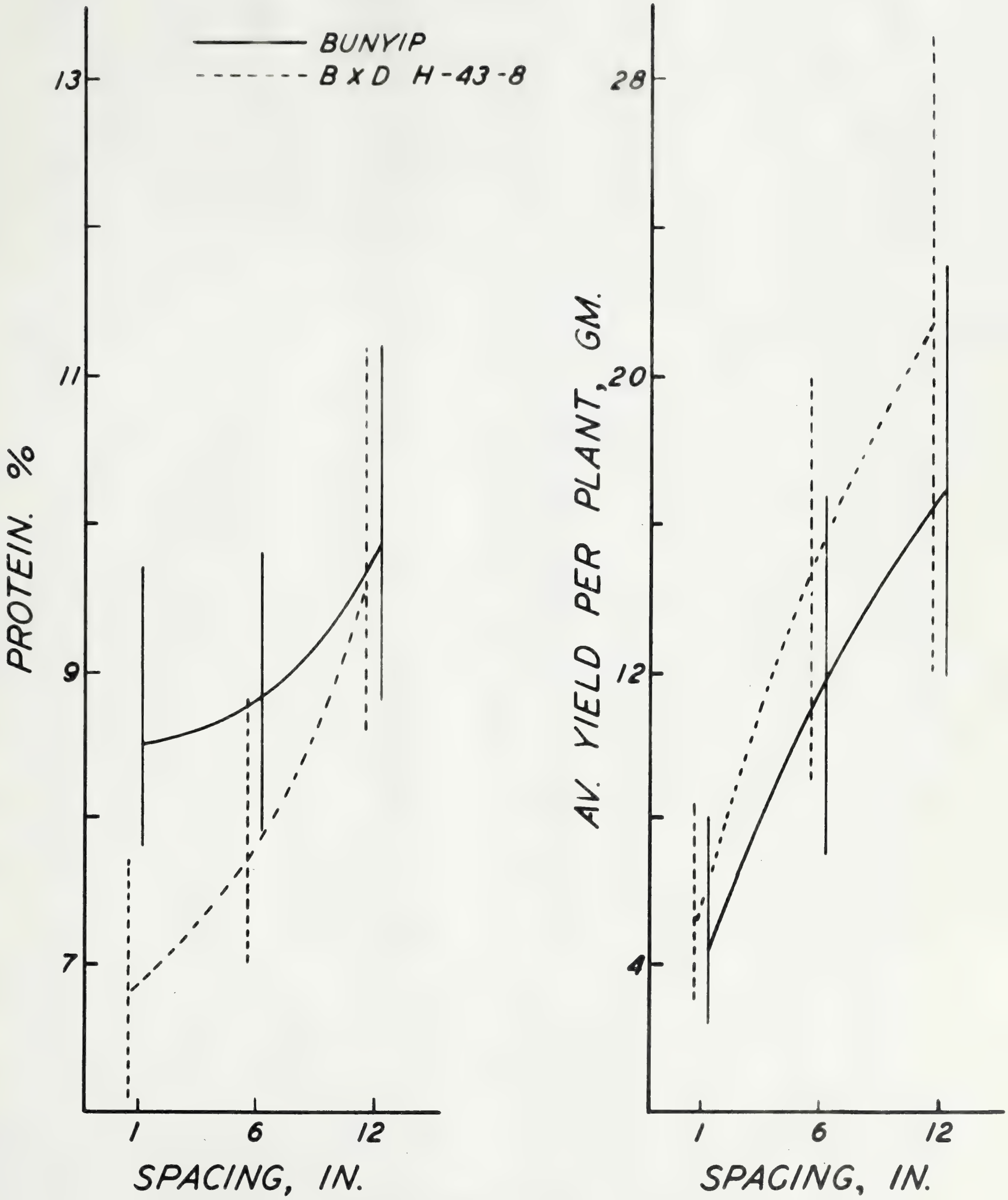

Figure 4

Effect of spacing on mean yields per plant, mean protein contents, and yield and protein content ranges of wheat
Fallis, 1946

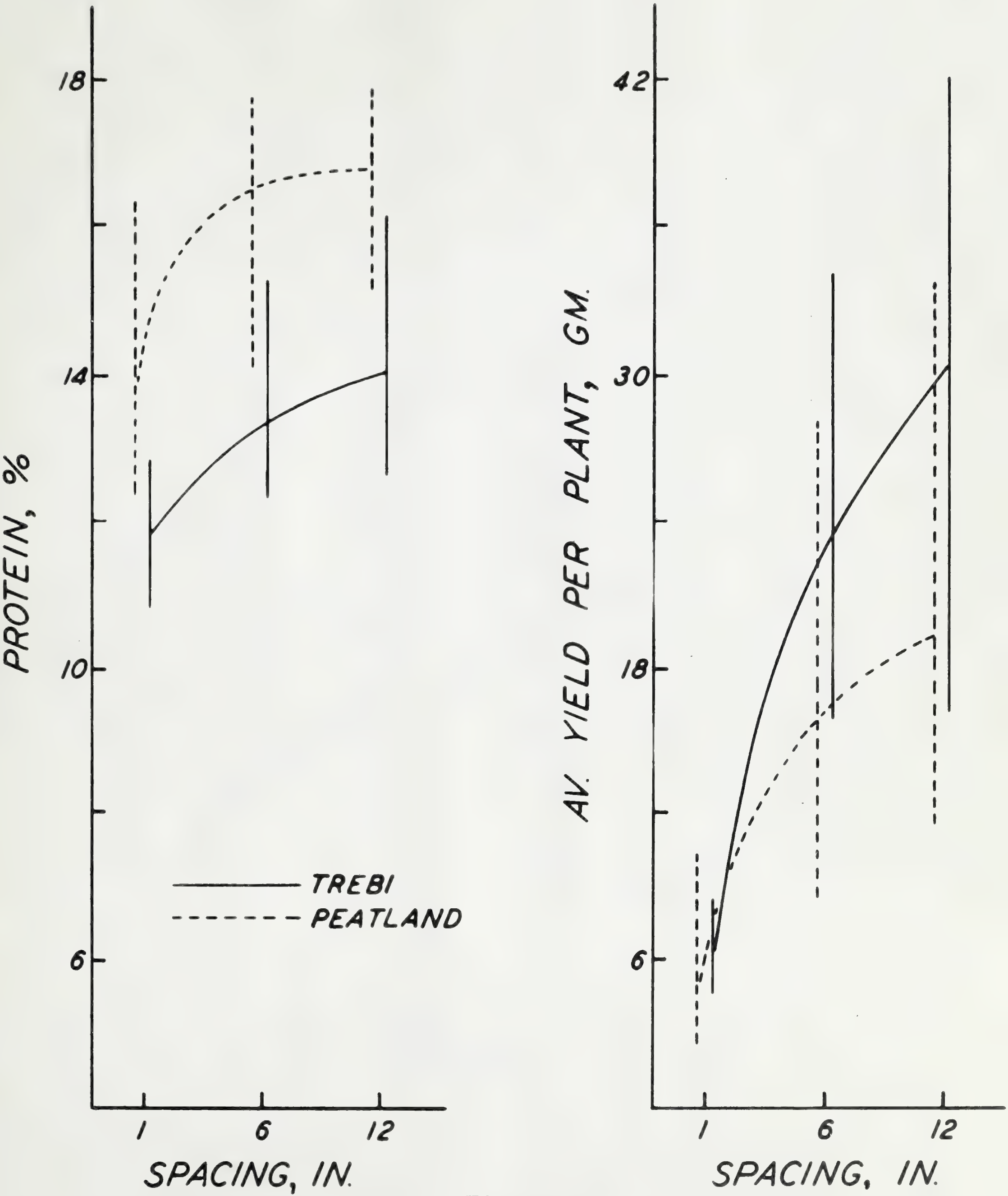

Figure 5

Effect of spacing on mean yields per plant, mean protein contents, and yield and protein content ranges of barley
Edmonton, 1946

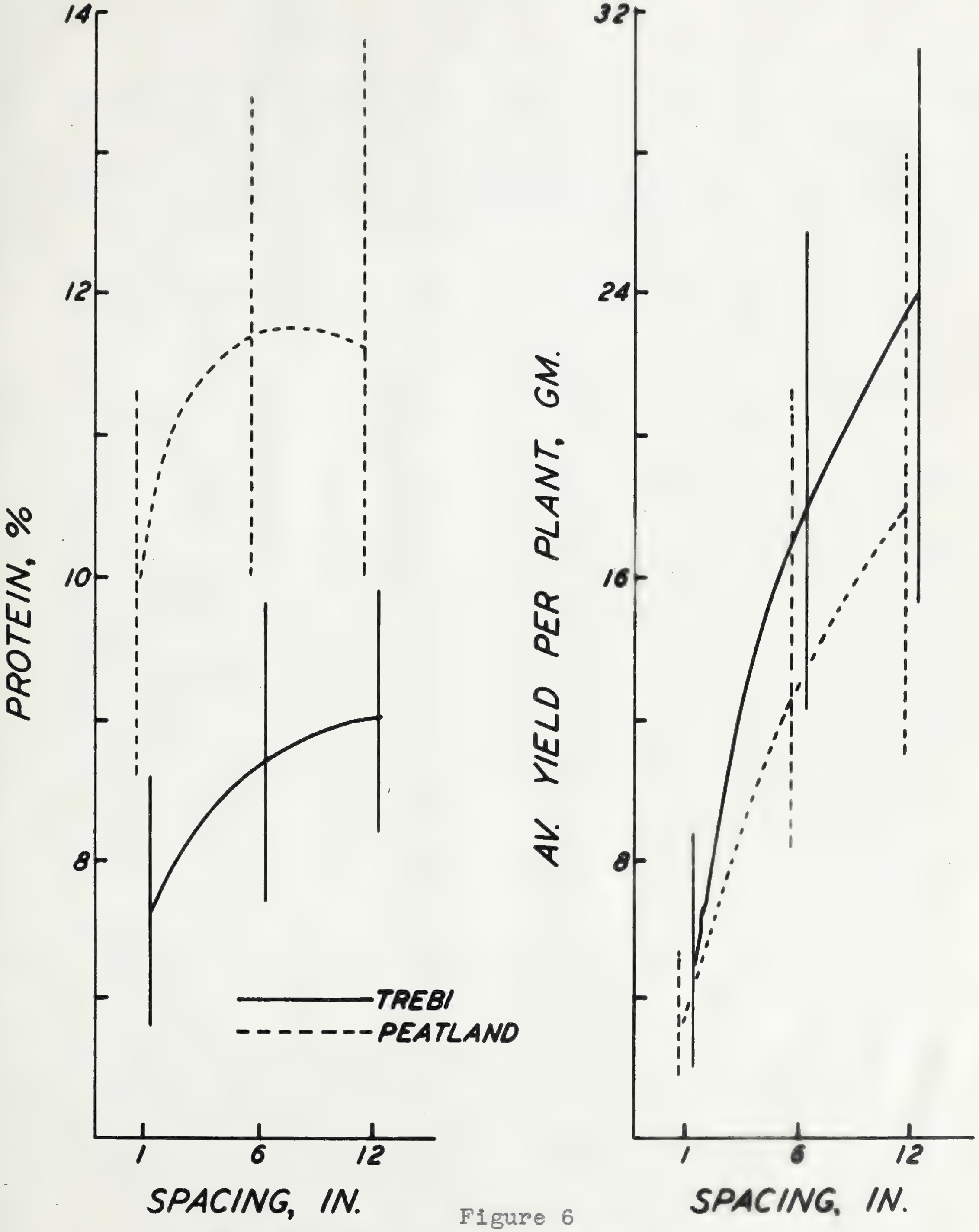

Figure 6

Effect of spacing on mean yields per plant, mean protein contents, and yield and protein content ranges of barley
Fallis, 1946

relation coefficients are not given for this study.

For both varieties of wheat and barley increased spacings were accompanied by increased mean yields per plant and increased ranges of yields within the spacings. In all cases the increases in mean yields were greater between the one- and six-inch spacings than between the six- and twelve-inch. In Figures 3 to 6 it can be seen that increased spacings gave smooth yield increases, with a gradual decrease in unit increase as the wider spacings were approached. For the wheat at Edmonton the slight increases in yield between the six- and twelve-inch spacings were probably due to the immaturity of the twelve-inch-spaced plants when harvested. Throughout the four tests the higher-yielding variety increased at a greater rate than did the lower-yielding one. As was the case for mean yields, greater spacings caused an expansion of the yield ranges, the rate of expansion becoming less as spacings were increased.

Except in the case of Bunyip at Edmonton, all varieties of wheat and barley exhibited an increase in mean protein content as spacings were increased. For the Bunyip at Edmonton there was a decrease in mean protein content with increased spacings. At Edmonton the decrease and increase for Bunyip and Bunyip x Dicklow H-43-8 gradually fell off as spacings were increased, while the increases for both varieties at Fallis were greater at the wider spacings. For

barley at both stations all increases gradually decreased in unit increase as the wider spacings were approached. Peatland at both stations had the more rapid increase up to the six-inch spacings and then fell off more rapidly toward the twelve-inch spacings. At both stations the lower-protein variety of wheat showed the greater increase in mean protein content, and the higher-protein variety of barley the greater increase with increased spacings.

The protein content ranges showed no definite relationships to spacing increases. While the yield ranges were for the most part nearly as large as the mean yields the ranges of protein contents were small, ranging from 1.0 to 4.0 percent protein or from 10 to 30 percent of the mean proteins. All wheat results, except those for Bunyip at Edmonton, showed a marked increase in protein content ranges with increased spacing. Bunyip tested at Edmonton, the only instance in which increased spacings gave a decrease in average protein content, showed no consistent change in ranges of protein contents. For barley the results were inconclusive. For Trebi, increased spacings were accompanied by an increase in the ranges of protein contents at Edmonton, while at Fallis there was no change in the ranges. For Peatland, increased spacings caused a consistent decrease in the range of protein contents at Edmonton and a consistent increase of the same magnitude at Fallis.

Discussion

In all instances throughout this study increased spacings gave corresponding increases in average yields per plant. This agrees with the results obtained by Engledow and Ramiah (5). For all tests except that of the wheat varieties at Edmonton, the rate of increase gradually diminished as the wider spacings were reached, indicating that the maximum possible yields would have been reached at spacings of somewhat greater than twelve inches between plants. At Edmonton the increases in mean yields per plant, for both varieties of wheat, between the one- and six-inch spacings were similar to those obtained in the other tests. However, the increases between the six- and twelve-inch spacings were very small. This inconsistency was at least in part due to the fact that because of the lateness of maturity of the plants at the twelve-inch spacings they had to be harvested before they were completely mature. For all tests increase in spacings caused a greater rate of increase in the average yields of the higher-yielding variety than it did for the lower-yielding one. From this it would appear that the variety with the greatest inherent yielding ability makes the most efficient use of the increased availability of moisture and nutrients resulting from the spacing increases.

In the case of wheat at both Edmonton and Fallis,

increased spacings caused a much greater increase in average protein content per plant for the variety with the lower protein content than it did for the variety with the higher protein content. Keeping in mind the negative relationship between yield and protein content, it would appear that at Fallis, where the soil is deficient in nitrogen, the effect of increased yield was more than offset by the increase in nitrogen availability caused by the increase in spacing. Thus, with increased spacings, an increase in average protein content was obtained for both varieties. At Edmonton, where there is more nitrogen in the soil, the effect was not so extreme. The low-protein Bunyip x Dicklow H-43-8, which showed the greater increase in average protein at Fallis, gave a much smaller increase at Edmonton. For the high-protein Bunyip, which showed the smaller increase in protein content at Fallis, the positive effect due to increased availability of nitrogen was not sufficient to offset the negative effect of increased yield. Thus, a decrease in protein content resulted.

In the barley tests at both Edmonton and Fallis, the average protein content of the high-protein Peatland showed a much greater positive response than did that of the low-protein Trebi when the spacing was increased from one to six inches. However, for the increase in spacing from six to twelve inches Trebi showed the greater response. The increase in average protein content of Peatland was rapid

up to the six-inch spacings and then appeared to have reached its maximum protein content, with the indication that still greater increases in spacing would cause no greater increase in protein content and possibly a decrease. Trebi, on the other hand, although increasing more slowly at first, did not appear to have reached its maximum protein content at the twelve-inch spacings, indicating that a still greater protein content would have been obtained by greater spacing increases.

Throughout these tests there appears to be a variation in the ability of varieties to use the increased amount of nutrients made available by increased spacing. When spacings were increased there was a variation in varietal reaction, but no variation in reaction between stations. When spacings were increased the higher-yielding variety of the pair always increased in yield at a greater rate than did the lower-yielding one. This indicates the ability of the higher-yielding variety to make more efficient use of the increased nutrient supply. Because of the negative yield-protein relationship existing for both wheat and barley, it would seem reasonable that the variety giving the greater yield increase per unit spacing increase would give the smaller increase in protein content. Although the increase curves for the two barley varieties are quite different this appears to be the case. However, for the two wheat varieties

this does not hold true. The variety that gave the greater increase in yield with increased spacing also gave the greater increase in protein content.

For the wheat tests at both Edmonton and Fallis the average varietal yield ranges for the individual plants at the one-inch spacings were all approximately 5 grams. For the barley tests these ranges varied from approximately 4 to 8 grams. These ranges were somewhat smaller than those obtained by Clark and Quisenberry (4) using Marquis and Koto wheats. In the present study the yield ranges of the six-inch spacings showed large increases over those obtained for the plants at the one-inch spacings. The average ranges for the plants at the twelve-inch spacings also showed increases over the ranges obtained at the six-inch spacings, although these increases were not so large. Thus there is formed the same picture for range increase as for yield increase; the range expanding, but at a diminishing rate, as the wider spacings are approached.

The wheat results appear to indicate that there is a positive association between mean protein contents and ranges of protein contents, as effected by spacings. The barley results, however, show no general trend. The scope of the experiment is not great enough to determine whether these inconsistencies in the range trends are the true picture or not.

There was no association found between the yields

and protein contents of the individual plants. This does not agree with the results obtained by Clark (3) who found significant negative correlations between the yields and protein contents of individual plants of both F_2 and F_3 hybrids of Marquis x Hard Federation crosses. That this lack of consistency is due to the small ranges of yields and protein contents encountered in the present study is indicated by the work of Clark and Quisenberry (4) who found that both the yield and protein content ranges of individual plants of a Kota-Marquis cross were much larger than the corresponding ranges for the individual plants of either of the parents.

Owing to the variations in yield and protein content of individual plants within a variety and the lack of association between the two, it appears that the protein contents of individual plants cannot be used as an indication of either the potential yielding ability or protein content of a selection.

GENERAL DISCUSSION

A careful analysis of the relationship between yield and protein content of cereal crops is deemed important. For many years emphasis in testing of cereal crops has been on yield, the general assumption being that protein content remained constant. However, in recent years the importance of protein content has become more widely recognized. Several factors have contributed to its increasing importance, at least as far as cereal crop production in Alberta is concerned. With the introduction of earlier wheat varieties, production has been encouraged farther and farther north into areas where the environmental conditions are not conducive to high protein content. Soft white wheats are and will be produced in Alberta, and in these wheats a low protein content is required. Also, at some date in the future, it may be possible to achieve the grading of wheat on the basis of its protein content. It is believed, however, that studies of the yield and protein content of cereal crops should not be independent but closely integrated. In this belief, investigations have been initiated to determine the effects of various factors on the yield-protein relationships of wheat and barley.

The results from a three-year test of hybrid lines from a single cross of both wheat and barley indicate that there is a negative relationship between protein content and

yield. Data for 1944 and 1945 were obtained by Grant (6), and data for 1946 are included in the present study. The size of the correlation coefficient apparently bore no relation to location, season, or crop. Tests on gray wooded soils and tests on black soils gave similar correlations. In years with adequate moisture and high yields the correlations were not consistently higher or lower than in dry years. The comparable results for wheat and barley were not unexpected. Berg (2) has shown a negative relationship between the yields and protein contents of selections of winter wheat from the same cross. Grant (6), in reviewing the literature on the subject, found that in general there was a negative relationship between yield and protein content.

This negative correlation between yield and protein content suggests many problems and avenues of research for the plant breeder. Perhaps the most pertinent question is: What limit does this negative relationship between yield and protein content set on the breeding of high-yielding-high-protein wheat? As yet this question cannot be answered. It would also be of value to know whether this relationship is physiologically or genetically determined. The total quantity of protein produced varies within narrow limits, whereas the total grain yield fluctuates over a wide range. It is thus possible that protein content is just a physiologically controlled function of yield; as yield increases protein content decreases, simply because only a limited quantity of protein

can be produced. On the other hand, when one considers the large difference in protein contents between hard and soft wheats, it seems possible that there are genetic factors for increased protein content and, on the basis of the negative correlation between yield and protein content, genetical linkage between the two. It is believed that the negative relationship demonstrated to exist between yield and protein content should be studied more critically to determine to what extent this relationship has a physiological, and to what extent a genetical, basis.

Grant (6) suggested that the negative relationship between yield and protein content might be used in discarding, on the basis of protein content alone, the undesirable selections from a population at early stages of a breeding program. He felt that head-row or other material in early stages of testing might be analysed for protein content and, if the breeding objective was a low-protein-high-yielding wheat, only the low-protein selections retained. On the other hand, if a high-yielding-high-protein wheat was desired a compromise would have to be made; the high-protein selections would have to be discarded because they, in all probability, would be low yielding, and the low-protein selections would have to be discarded because they, as such, would be undesirable.

The present study gave conclusive evidence as to

the feasibility of using this method of elimination. Protein contents of head-row material cannot be used as reliable indications of the yielding ability of selections. Owing to the influence of soil variations upon the non-replicated plots of the head row tests, the protein contents showed varying degrees of accuracy when correlated with their related values in the yield trials, thus would show varying negative relationships if correlated with the yields of the yield trials. Correlation coefficients were higher when the head-row material was sown at spacings of one inch than when sown at spacings of six or twelve inches. The best correlation between the protein contents at the one-inch spacings and those of the yield trials was found for the wheat at Edmonton. However, even in this case, it was found that protein determinations from the head-row material could not be used as accurate estimates of the yielding ability of the hybrid lines. Out of the 50 hybrid lines considered, 10 were predicted as being low yielding and 10 as being high yielding, on the basis of the protein results of the one-inch spacings. When checked against the results of the 1946 yield trials the prediction was right in two cases for the high yielding estimates, and in six cases for the low yielding estimates. The accuracy of yield estimate was slightly less when the comparison was made between the protein contents of the head-row material in 1946 and the same material in 1944 and 1945. The analysis of head-row material was slightly more efficient in estimating low-

yielding selections than in estimating high-yielding. In general, however, protein determinations of head-row material produced an elimination only slightly more accurate than could be expected from a random elimination of selections from a population. When it is considered that the accuracy of the protein contents used for this elimination are better than could usually be expected, and that head rows are usually sown at varying spacings, these affecting the protein contents, it will be realized that protein contents of head-row material cannot be used to estimate the potential yielding ability of hybrid material.

It has been mentioned that seeding rate has an effect on protein content. This has been shown in the present study where the spacing of plants in rows one foot apart was varied from one to six to twelve inches. Such spacings would correspond approximately to seeding rates of 70, 12, and 6 pounds per acre. In the case of wheat and barley at Fallis and barley at Edmonton increased spacings, thus decreased seeding rates, were accompanied by increases in protein content. Wheat at Edmonton showed a decrease in protein content with increased spacing of plants. It should be realized, however, that the widely different seeding rates of this study resulted in wide differences in the date of maturity. From a practical point of view it is realized that seeding rates of six and twelve pounds per acre are impossible. However, they have served in indicating the

trend of protein contents with increased spacings at each location. Because at each location this trend in protein contents was apparent with the different seeding rates, it would seem desirable to investigate the effect of rates of seeding of a less extreme nature on the protein contents of different wheat and barley varieties.

Since it was found that protein contents of head-row material could not be used to estimate the yielding ability of hybrid lines, it is to be expected that the protein contents of individual plants would be even less reliable in the same respect. This was found to be the case in the present study. Actually there was no correlation between the yields and protein contents of individual plants. From this study there arises the problem: what amount of plant material is necessary and under what conditions should it be grown to get the most accurate determination of protein content? It has been shown that there is a continued improvement in the accuracy of the protein determination from a single plant, through populations spaced twelve and six inches apart to material sown at a one-inch spacing. Apart from the estimation of yield from protein contents, particularly in the case of soft wheats where a low protein content is necessary, careful consideration will have to be given to protein content alone. It is known what constitutes a reliable test of yield for hybrid material, but little is known of the plot size and design required to give the most reliable comparative estimates of protein content.

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SUMMARY

There are three sections to this investigation. The purpose of the first section was to substantiate the work carried out by Grant, and to give continuity between his work and the work undertaken in the second section of this study. The purpose of the second section was to investigate at least in part the errors entering into the use of the yields and protein contents of early generation hybrid material as indications of the potential yielding ability of selections. The third section was a study of the effects of spacing on the yields and protein contents of individual plants.

Working with 50 random selections of a Bunyip-Dicklow cross and 50 random selections from a Trebi-Peatland cross (selected from the 100 selections of each used by Grant) highly significant negative relationships between yield and protein content were obtained. The correlation coefficients were similar to those obtained by Grant during 1944 and 1945 working with the 100 original selections of each cross. The relationships also compared with that found for winter wheat by Berg, working with 48 selections of the cross (Bankuter 178 x 3922) x Aring.

The purpose of the second section of the study was to determine the effect of plant spacing on yields and protein contents, and also the effect of soil variations on the yields and protein contents of the non-replicated 5-foot rows used when working with early generation hybrid material. The same 50 selections of wheat and barley as used in

the first section were sown at spacings of one, six, and twelve inches in non-replicated 5-foot rows. At both Edmonton and Fallis increased spacings were accompanied by increased yields per plant. For all tests except the wheat at Edmonton increased spacings gave increases in protein content. At Edmonton with increased spacings the protein content of wheat showed a decrease. Correlation coefficients were calculated for the relationships between the yields and protein contents at the different spacings, the spacing yields, and the corresponding yields of the yield trials, and the spacing protein contents and those of the yield trials. These indicated that soil variations had less influence on yields and protein contents of the selections at the one-inch spacings than at the other spacings. On the whole, soil variation seemed to have as great an effect on protein content as on yield.

Using the results of the one-inch spacings showing the greatest apparent accuracy the efficiency of the use of yields and protein contents in eliminating the undesirable selections from the population was calculated. On the basis of a 40 percent elimination, the results obtained when using either yield or protein content as the criterion of elimination were only slightly better than would have been obtained by a random discarding of the selections from the population. It was therefore concluded that neither yields nor protein

contents of early generation hybrid material can be used as a basis for the elimination of high-yielding-low-protein or low-yielding-high-protein selections from a population.

When the yields and protein contents of single plants from standard varieties were studied, large variations in both yield and protein content were obtained within the varieties. The range of variations for yield was larger than for protein content, and for both yield and protein content the ranges increased in magnitude with increased spacings. In no case throughout the study was there a significant relationship found between the yields and protein contents of the individual plants.

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